HEAT EXCHANGE IN COOLING A GENERATOR GAS IN AN EDDY-GENERATING BUBBLING APPARATUS


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We present results of an experimental investigation of the contact heat exchange between a liquid and a gas in a vortex bubbling layer for initial temperatures of the gas of up to 300°C and carry out a comparison with a previously obtained relation for lower temperatures.

The high heat- and mass-exchange characteristics of eddy-generating bubbling contact apparatuses provide good possibilities for their use in various fields of engineering and technology. A developed interphase surface and the high degree of its renewal and mixing make it possible to intensify substantially the processes of transfer in comparison with traditional devices.

At the present time, there are a sufficient number of works devoted to the study of the various characteristics of eddy-generating bubbling apparatuses and, in particular, the coefficients of heat exchange between the gas and the liquid [1-3]. However, the relations given in these works were obtained for relatively low gas temperatures (of up to 100°C), whereas higher temperature levels are characteristic for many of the cases of contact heat and mass exchange (utilization of the heat of tail gases, a number of chemical-technology processes). Justified calculation and design of eddy-generating bubbling apparatuses require an investigation of the heat- and mass-exchange characteristics in a wider temperature range.

The aim of the present work is to study the heat- and mass-exchange characteristics of eddy-generating bubbling apparatuses in cooling of gases with temperatures of up to 300°C.

The scheme of the device is shown in Fig. 1. For the purpose of simultaneously cooling and cleaning the generator gas, an eddy-generating bubbling apparatus with an immobile casing was installed at the exit of a reversion-type generator, which operated on wood wastes. The apparatus consisted of gas distributor 1, guiding device 2, top cap 3, and ring 4, which determined the thickness of the bubbling layer. The generator gas was supplied to the apparatus through branch pipe 5, it exited through separator 6, and then it was burned in burner 7. Liquid (water) was delivered tangentially to the upper portion of the layer and was drained through branch pipe 8.

The guiding device consisted of 12 tangentially located blades that formed gas-supply slits of width 1 mm and height 20 mm, which corresponded to the height of the vortex chamber \( h_{ch} \). The inside diameter of the swirler was 100 mm (the relative flow cross section was equal to 3.82\%) and the thickness of the bubbling layer \( H_{layer} \) was 15 mm.

In the experiments we measured the hydraulic resistance of the apparatus, the flow rates of the liquid and the gas, their temperatures at the entrance to the apparatus and the exit from it, and the gas composition.

The gas temperatures were determined by Chromel-Alumel thermocouples, and the liquid temperatures, by mercury thermometers graduated to 0.1°C. The flow rates of the gas and the liquid were measured by rotameters 9 and 10. Upstream of the rotameter 9 a changeable filter 11 was installed. The gas flow rate was measured periodically by switching of valves 12 and 13. The gas composition was determined by drawing samples with subsequent analysis on a chromatograph.
The coefficients of viscosity and thermal conductivity of the gaseous mixture, which are necessary for processing the results, were calculated respectively by using the Mann and Wilkie formulas. From relations given in [1, 3, 4], we also calculated the speed of rotation of the gas-liquid layer, the diameter of the bubbles, and the volumetric gas content.

In all, 35 series of experiments were carried out. The main operating parameters of the experiments were: the gas flow rate $G_g = 9 \ldots 13$ g/sec; the liquid flow rate $G_{liq} = 35 \ldots 60$ g/sec; the gas temperature at the inlet of the apparatus $t_{lin.g} = 50 \ldots 300^\circ$C; the mean composition of the gas (vol.%): CO 20; H$_2$ 14.5; CO$_2$ 11.3; N$_2$ 52; CH$_4$ 1.5; Ar 0.6; O$_2$ 0.1.

Figure 2 presents data on the hydraulic resistance of the eddy-generating bubbling apparatus as a function of the gas velocity in the slits of the swirler. Results of [4] for an apparatus with a slit-type swirler are also presented here. As is seen from the figure, installation of the vane guiding apparatus leads to a considerable decrease in the hydraulic resistance. The values of $\Delta p$ in the case of operation on the generator gas turned out to be smaller than with operation on air, which is associated with the lower density of the gas. The solid line shows the resistance of the gas-liquid layer, which corresponds approximately to $\rho_g w_0^2/2$ ($w_0$ is the gas velocity in the slits, since in the gas-liquid layer virtually all the kinetic energy of the tangentially supplied gas is lost).

In processing the heat-exchange results, we determined the values of the mean coefficient of heat transfer from the relation

$$\alpha = \frac{Q_g}{F(t_{m.g} - t_{m.liq})},$$

where $F = a V_{layer}$; $a = 6\varphi/d_{bub}$; $V_{layer} = \pi h_{ch} H_{layer}(R_{ch} + R_1)$; $R_{ch}$ and $R_1$ are the outer and inner radii of the gas-liquid layer; $t_{m.g}$ and $t_{m.liq}$ are the mean temperatures of the gas and the liquid; $\varphi \approx 0.7$.

Under the present experimental conditions gas cooling occurred, i.e., the heat released by the gas was spent on heating and evaporation of the liquid. Data on heat exchange for some of the experiments are listed in Table I. Within one experiment, the gas temperature at the inlet of the apparatus increased with time, which was associated with heating up of the elements of the working channel.

The results were processed in the form of the dependence of the mean number $Nu = a d_{bub}/\lambda_g$ on $Re = w_{bub} d_{bub}/v_g$, where $w_{bub} = G_g/(\rho_g 2\pi R_{ch} h_{ch} \varphi)$. The dependence $Nu = f(Re)$ for different apparatuses is given in Fig. 3. As seen from the figure, the heat exchange in the rotating gas-liquid layer is several times more efficient than that in traditional bubbling apparatuses. This result is achieved first of all due to a developed interphase surface and the high degree of its renewal.